Stand structure and habitat diversity on a private farm forestry estate in northern Tasmania.

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Abstract

Stand structure, floristic diversity and forest habitat condition were recorded and analysed for five contemporary silvicultural regimes in native *Eucalyptus obliqua* forest and young *E. nitens* plantations on the one private forest estate in northern Tasmania. The location is a diverse 760 ha forested property in the Northern Midlands, on the eastern foothills of the Great Western Tiers. A replicated series of small sample plots was established in 2007 and the plot survey was extended and remeasured in 2013. In 2007, stand structure, floristic composition and habitat condition were first compared for *E. nitens* plantations on ex-pasture and ex-bushland sites and for thinned *Eucalyptus obliqua* native forest, advanced regrowth *E. obliqua* forest and reserved oldgrowth *E. obliqua* forest, respectively. In the 2013 survey, two distinctly different methods of habitat assessment were applied and results were compared among the three native forest regimes. The mix of silvicultural strategies was also assessed in terms of overall tree growth and production strategies of the private farm forestry enterprise.

Indices of floristic diversity and habitat condition strongly favoured the silviculturally managed native forest and reserved oldgrowth forest. Results for both native forests and plantations were closely aligned with altered regeneration dynamics following respective (and notably different) histories of disturbance. The study demonstrates that for small scale private forestry in Tasmania, there is opportunity for an integrated mix of native regrowth forest to be silviculturally managed alongside remnant old-growth eucalypt forests and young eucalypt plantations, in order to achieve favourable outcomes for both wood production and biodiversity protection across the landholding as a whole. With careful planning and skilled forest management, this creates a broad basket of social and community benefits as a consequence of achieving both the environmental and commercial goals of the enterprise.

INTRODUCTION

This research addresses the twin goals of sustainable biodiversity protection and commercial wood production in a silviculturally managed private forestry estate. Two adjoining properties were purchased by the private forest owners John and Diana Lord in 1985 and 1990 respectively (AFG 2005). The former, called *Springmount*, consisted mostly of derelict farmland and heavily cut-over native eucalypt forest in an unmanaged state, the latter being *The Springs* which largely supported an expanse of young even-aged native forest of *E. obliqua* which had regrown following the previous owner's clearfelling for woodchipping some fifteen years earlier.

The combined private forest estate of area 760 ha has been continuously and actively managed on a well-planned silvicultural basis for the past 25-30 years since purchase by the present family owners. There are property management plans, financial plans and state-approved forest practices plans for the mix of forest management regimes, including both *E. nitens* plantations and silviculturally managed native forest. Respective coupes have been delineated and mapped for native forests and plantations respectively, according to forest type, species, silvicultural history and proposed future harvesting and reinvestment.

Practical objectives of the farm forestry enterprise were to:

1. Provide a financial resource for the family for the education of the children and for the owners’ future retirement.
2. Provide a sustainable supply of domestic wood products, including both for commercial sale and for on-farm applications such as rough-sawn timber, roundwood for fencing and firewood.
3. Provide an opportunity for family recreation.
4. Contribute in a tangible manner to local employment and to the region’s rural economy.
5. Enable the landholders to obtain first hand knowledge of the practice of private forestry in both a commercially and ecologically sustainable manner.
6. Demonstrate to other client growers how to manage their own forests and plantations.

The underlying management strategies have been to divide the forests into land management zones and operational coupes; to retain native forests where reasonably well stocked; and to convert previously degraded forest and derelict farmland to more productive plantations. Accordingly, management plans for *Springmount* and *The Springs* provide for a carefully designed matrix of native eucalypt forest, hardwood and softwood plantations, forest reserves, retained grasslands and some access roading.

Wood harvested as thinnings from native forests has been sold as sawlogs and wood fibre for pulp production. The focus is now on adding longer term value to produce a sustainable mix of veneer logs, sawlogs, wood fibre, fuelwood and preservation material. Early thinnings of *E. nitens* have been used for sawlog, high quality wood fibre and some preservation material which was treated for the family's own use. The forest landholders have been building up a sizeable stock of sawn and air-dried timbers both from their own forests (*E. delegatensis, E. obliqua, E. viminalis* and *A. melanoxylon*) as well as timber salvaged from other local sources. These timbers have been used extensively in the building of their home in the forest (plates, studs, beams, lining boards, flooring, window frames, doors and furniture), farm buildings (structural timbers and doors and windows), yards (posts and rails) and some bridgework on the property.

The forestry enterprise is meeting sustainable commercial objectives. Detailed financial forecasts have been prepared by the owner-managers, including estimated harvest costs, wood yields and products prices, establishment and pruning costs, and rates and insurances for plantations established during 1985-2001, to determine net cash inflows and outflows. The owners have also prepared estimates of net cash flows for stand improvement (silvicultural thinning), roading and harvesting sequences of the managed native forests.

Plantation budgets were forecast on growth rates achieving a Mean Annual Wood Volume Increment (MAI) of 15 m^3 ha^{-1} an^{-1} over the life of the rotation. Average MAI to date of first thinning (1989-1995) equalled 12 m^3 ha^{-1} an^{-1} and some of these increments were achieved in broken stony country at higher elevations within the property.

Sale of selected silvicultural thinnings of mature *E. obliqua* native forest for sawlog and pulpwood in year 2000 (labelled Timber Stand Improvement, or TSI) was sufficient to pay for the establishment of new plantations on neglected pastures on lower flats during 2001. The native forest estate is also successfully managed for multiple uses – forest production, landscape and biodiversity protection, recreation, scientific research and education. The results of the following stand analysis and forest habitat and biodiversity assessments provide a valuable measure of the success of this private forestry enterprise.

METHODS

A series of replicated small sample plots was first established in 2007 in order to provide a comparative snapshot of forest structure, floristic diversity and habitat condition. Observations were replicated across multiple small plot samples in each of five principal forest management zones on the property, *viz.* in young eucalypt plantations (ex-pasture and ex-bushland sites respectively), silviculturally managed native eucalypt forests (both unthinned regrowth and thinned original 'high' forest), and in reserved oldgrowth eucalypt forest.

Stand structure, floristic composition and habitat condition were first described in 2007 and reported by Unwin *et al.* (2008). Results were compared for *Eucalyptus nitens* plantations on ex-pasture and ex-bushland sites and for thinned *E. obliqua* native forest, advanced regrowth *E. obliqua* forest (following clearfell in the seventies), and reserved oldgrowth *E. obliqua* forest, respectively. The original plot survey was remeasured and extended in 2013 when a second distinctly different method of forest habitat assessment was applied (after McElhinny *et al.* 2006), alongside the original TasVeg. methodology (Michaels 2006).

Results for the TasVeg. (*'Habitat Hectares'* style) assessment of 'habitat condition' are compared here for the three native forest regimes in common to both the 2007 and 2013 surveys on the same sites. The 2013 TasVeg. results are also compared with independent results for 'habitat complexity', as derived concurrently on the same native forest sample sites using the methodology adapted from McElhinny *et al.* (2006) and calibrated for dry eucalypt forests elsewhere in the Midlands of Tasmania (Bailey 2012).

The study site and silvicultural regimes

'Springmount' is a 200 ha property located high in the foothills of the Western Tiers in northern Tasmania (Lat. 41^{o} 43'S, Long. 146^{o} 53' E) (Figs. 1 and 2). *Springmount* adjoins *The Springs,* a 560 ha property which rises from the agricultural plain and is located on the lower slopes and flats, due north of Blackwood Creek. Prior to European settlement, the vegetation was largely native forest of *Eucalyptus obliqua, E. viminalis* and *Acacia melanoxylon,* with *E. delegatensis* on the upper slopes and mixtures of *E. obliqua*, *E. ovata* and some *A. dealbata* and *Melaleuca ericifolia* on the lower slopes and flats. The elevation range is 200 m to 550 m ASL. The immediate backdrop is the Western Tiers and Central Plateau at 1,200 m elevation, overlooking and protecting the forest properties from prevailing westerly and south-westerly winds (Fig. 1). Average annual rainfall is approximately 1,000 mm.

On the plains and footslopes, shallow soils overlay clay, and as the elevation increases, mud-stone derived soils and then broken rock and shale are common. Hard dolerite protrusions form a level surface at several elevations, creating a series of steps or benches dissected by a small number of streams which are sourced in permanent springs at the edges of benches and platforms higher in the landscape.

[Insert Figs. 1 and 2 near here]

Springmount and *The Springs* together share a north/north-easterly aspect. Dry eucalypt forest with a fire-prone heathy understorey predominates on the north and north-east slopes and some wet eucalypt forest remains on the southern slopes and in some eastern gullies. The two adjoining properties are hereafter referred to collectively as the Lord family forests, or simply 'the forests'. For present purposes, the forest management zones are labelled A-E, based principally on forest type and the applied silvicultural regime. On the ground, these zones are further divided into operational coupes (AFG 2005).

Springmount was part of a bush run which in parts had been heavily logged for sawlogs and some pulpwood in the 1970s. Regeneration of tree species was poor and patchy and hence the vegetation was classified by the then Private Forestry Division, Tasmania as 'derelict forest'. The grassland area had been neglected and had been leased to a local farmer for summer grazing of sheep. During 1985-1992, *E. nitens* plantations were established by the present owners on both the ex-pasture and degraded forest (ex-bushland) areas respectively (Fig. 2 and AFG 2005).

Dry *E. obliqua* forest of *The Springs* had been heavily logged and clearfelled in the mid-1970s as a chipwood concession and now consists of densely stocked sapling and pole regrowth of *E. obliqua* aged about 40 years. The mid-slopes area now includes young *E. nitens* plantations whose establishment commenced on ex-pasture (1985) and on heavily cut-over bush sites (1986) with a planting program which continued through to 1992 (Figs. 1 and 2). Although not part of this study, some *Pinus radiata* plantations were also established on the lower slopes and flats, in 1997 and 2001. On the flats, there are also some remnant patches of riparian forest containing heavily disturbed stands of *E. ovata, E. viminalis, M. ericifolia* and some *E. obliqua.*

Of the 760 ha total area of the two properties, 239 ha is presently managed as *E. nitens* plantations for pulpwood thinnings and future sawlog. Apart from a smaller area of young *P. radiata* plantation (45 ha) and clearings for a cottage and road easements (<10 ha), there remains 466 ha of native mostly dry *E. obliqua* forest in regrowth, thinned or remnant oldgrowth condition.

The Tasmanian Forest Practices System aims to achieve sustainable forest management with due care for protection of the environment. An integral component is the Forest Practices Code which provides scientifically based standards for environmental protection during timber harvesting and other forest operations (Forest Practices Board 2000). The Lord family’s farm forestry operations have exceeded the Code’s environmental standards, achieving excellent forest regeneration in thinned stands managed for timber production, as well as protection of significant riparian and remnant forest areas in reserves. The landholders also exercise tight controls on the environmental performance of their forest contractors.

Forest sampling and analysis

Contrasts in present-day forest structure were established using replicated small plot samples of five distinct forest silvicultural regimes across the two properties. The plots were defined by ground survey using GPS techniques and *a priori* delineation of TasVeg. forest types (Harris and Kitchener 2005) using a digital mapping layer and ArcView 3.2 (Ref. 1:25,000 scale, Liffey topographic mapsheet, enlarged to 1:15,000 scale).

The following five silvicultural regimes were selected and sampled based on contrasts in management history, their comparative silvicultural strategies and objectives, and existing forest structure and composition. All five regimes are important to the overall mix of objectives for forest management on the two properties, however the sequential order of Regimes A-E as listed below is of no particular significance other than for identification.

- **A.** Managed native forest dominated by *E. obliqua*, ('Dry *E. obliqua* forest' or DOB) with a fire-prone heath and shrub understorey, silviculturally thinned in 2000, for timber production, advanced-growth release and regeneration (loosely termed Timber Stand Improvement or TSI);
- **B.** *E. nitens* plantation, Coupe 5, now aged 25 yrs, established in 1989 on run-down ex-pasture, silviculturally thinned by 3^{rd} row removal for pulpwood at age 15 yrs (2004);
- **C.** *E. nitens* plantation, Coupe 6, now aged 22 years, established in 1992 on derelict (severely cut-over) forest, silviculturally thinned by 3^{rd} row removal for pulpwood at age 15 yrs (2007);
- **D.** Regrowth Dry E. *obliqua* forest, established following clearfelling for chipwood and burning for native regeneration, in mid-1970's (during previous ownership), now 40 years old;
- **E.** Reserved remnant (oldgrowth) 'Dry *E. obliqua* forest', intact, ungrazed and essentially unlogged (excepting for occasional isolated stems removed in the early 1900s).

The limited area of *Pinus radiata* plantation (45 ha) was excluded from the present study, as was the small unmanaged area of 'Dry *E. delegatensis* forest' (DEL) on the steep upper slopes.

The above silvicultural regimes (A-E) provided a framework for simple stratified random sampling of forest stocking, stand structure, crown projection and floristic diversity. Three replicated small-plot samples were surveyed in each forest regime during March-April 2007. Each small plot measured 20 m x 10 m (horizontal projection, area 200 m^2), on either flat terrain or on the contour on slopes facing N/NE. Vertical stratification of the forest profile was defined *a priori* in terms of canopy trees (diameter at breast height over bark, DBHOB $\geq$ 10 cm); small trees (>3 m height, $\leq$ 10 cm DBHOB) and small woody stems (1-3 m height, loosely called 'shrubs') in the understorey. Ground cover (<1 m height) was recorded in Braun-Blanquet Cover classes and where possible, by species and frequency. Within each sample plot, foliage projective cover (FPC) was derived using vertical projection of individual crown widths in two perpendicular planes which were aligned in the directions of the plot boundaries. FPC was then determined as the aggregate area of tree crowns (excluding overlap), expressed as a percentage of plot area. Floristic diversity was determined using Simpson's index D (1949) and the Shannon-Wiener Index H' (Shannon and Weaver 1948).

In August – September 2013, the previous (2007) sample plots in the three native forest regimes (A, D and E above) were each doubled in size to 20 m x 20 m (400 m^2) and two new replicate plots were added in the regrowth *E. obliqua* forest (D), to replace previous sample plots which were lost due to intervening harvesting. Apart from the enlarged plot areas, these native forest sample plots in regrowth, thinned and reserved 'oldgrowth' *E. obliqua* forest were remeasured according to the same procedures adopted previously in 2007.

Floristic diversity and habitat (biodiversity) assessment

In 2007, in each of the five forest regimes, including the young eucalypt plantations, an area of approximately 0.3 ha surrounding each of the small plot samples was assessed for forest habitat condition using the TasVeg. Ver. 1.0 Native Vegetation Condition Assessment method (Michaels 2006). TasVeg. condition assessment is an ecologically-based, semi-quantitative method developed by the Vegetation Section, Dept. of Primary Industries, Water and Environment, Tasmania for describing vegetation habitat in terms of prescribed ecosystem benchmarks for pre-defined vegetation types. Vegetation 'habitat condition' is ultimately described by a single aggregate ranking on a combined scale of 100, with component scores for specified ecological values or their surrogates (combined in the site condition score), and for patch size and connectivity in the surrounding landscape (Parkes *et al.* 2003, 2004; Michaels 2006). Component scores (with maximum weightings) are derived for presence and condition of large trees (10), tree canopy cover (5), lack of weeds (15), variety of understorey life forms (25), evidence and diversity of floristic recruitment (10), presence of organic litter (5), fallen logs (5), patch size (10), neighbourhood vegetation (10) and connectivity (5).

Although developed principally for use in native forests, the method has been applied here for the comparative description and ranking of forest habitat condition both in the observed forest plantations and in managed native forests. Plantation samples were assessed against corresponding benchmarks for original native forest types known to have existed on the respective sites prior to vegetation clearance (Harris and Kitchener 2005). In this study, TasVeg. field observations and analysis of habitat condition were applied concurrently but independently of the floristic analysis (by separate field technicians), in order to provide a valid comparison of independent results achieved in each approach.

In the 2013 survey, the previous TasVeg. assessment of habitat condition was repeated for the three native forest regimes (A, D and E) using the same techniques as previously but with a different crew of field technicians. For comparison with more recent habitat assessment techniques, the 2013 survey also applied a locally calibrated form of the McElhinny *et al.* (2006) method for analysis of 'habitat structural complexity', based on the same native forest sample sites as the 2007 and 2013 TasVeg. analyses.

The McElhinny approach provides a quantitative assessment of habitat complexity and understorey species richness. The original design by McElhinny *et al*. (2006) was specific to dry sclerophyll forests of the Southern Tablelands of New South Wales. The method was recalibrated by Bailey (2012) for application in Tasmanian dry sclerophyll forests (where *E. pauciflora* and *E. amygdalina* were the dominant tree species) and it was this calibration that was adopted here for use in the dry *E. obliqua* forests (DOB).

McElhinny's method of structural complexity analysis is comprised of the field assessment of 13 surrogate indicators (described here in Table 1). Each of the 13 indicators is allocated the same maximum, unweighted score of 10 and respective indicator scores are aggregated to give a total score for 'habitat complexity', out of maximum 130. For direct comparison with the TasVeg. results for habitat condition assessment, the structural complexity values derived in this study were finally proportioned to a scale of 100. In this study, the benchmark ranges of each indicator used in adapting and applying the McElhinny method of habitat complexity assessment were those derived from rescaled regression equations applicable in dry forests types encountered elsewhere in the Midlands of Tasmania (Bailey 2012).

[Insert Table 1 near here.]

Common sample plots were used for the respective methods of the TasVeg. 'habitat condition' and McElhinny 'habitat complexity' assessments which were applied in the 2013 survey.

Understorey species richness and vegetation cover were measured in three replicate quadrats of 5 x 5 m which were randomly located within each 20 x 20 m forest plot. Coordinates for each sample quadrat within the larger forest sample plots were generated with Google's random number calculator. Larger scale indicators including coarse woody debris (CWD, length of logs in two diameter size classes), abundance of large trees, dead trees and trees with hollows, and canopy cover estimates were measured in each of the three replicated (20 m x 20 m) sample plots located in each forest regime.

FOREST STRUCTURE AND COMPOSITION

Principal results of the 2007 and 2013 surveys are presented in Tables 2-6. The stand analysis indicates the physical and spatial contrasts in forest structure and floristic composition, attributed to current and past forest management practices. Stand data listed for native forest Regimes A, D and E show the comparative results of respective silvicultural and disturbance histories in the three distinct native forest regimes, including thinned and unthinned mature *E. obliqua* forest and 35-40 year old regrowth *E. obliqua* forest. Regimes B and C illustrate the contemporary plantation alternatives, with contrasting establishment of *E. nitens* on ex-pasture (B) vs. ex-bushland (C) sites, (with a small but possibly critical difference of three years in plantation age).

[Insert Tables 2 and 3 near here]

Tree density and tree size distribution are subject to silvicultural intervention (Table 2). Native forest stands in Regimes A and E represent thinned and unthinned Dry *E. obliqua* forest (DOB) which on these sites has never been cleared. Tree density, tree basal area and foliage projective cover each show expected contrasts in tree stocking and forest cover, due to tree selection and heavy silvicultural thinning in regime A, compared to near original condition in oldgrowth Regime E. Current tree basal area in the oldgrowth forest sample is very high (Tables 2 and 3), a result which is due largely to the long-term unlogged history of the forest (except in the early 1900s where few only stems per hectare were removed) and to the coincidence of several large specimen trees of *E. obliqua* in the small sample plots. (It should be noted that several of these are hollow or fire-scarred at the base.) By comparison, in Regime A, a marked reduction in stocking and cover of canopy trees is evident seven years following silvicultural thinning in year 2000.

In the plantation samples (Regimes B and C), tree height, basal area and canopy cover have each responded to a small but critical difference in plantation age, and possibly differing growth rate due to variation in the genetics of *E. nitens* seed sources. Stand density reflects recent thinning history**.** Foliage projective cover and tree size (basal area differences, Table 2) suggest that canopy development has been slower in the younger plantation of the ex-bushland plantation (Regime C).

At 2007, both the thinned *E. nitens* plantation of age 18 years (Regime B) and the unthinned regrowth *E. obliqua* forest of 35+ years in Regime D had each achieved a standing tree basal area equal to, or exceeding the post-thinning remainder in native *E. obliqua* forest in Regime A (Table 2). However, tree densities and size class distributions (eg. %BA on trees $\geq$60 cm DBHOB) differ within the respective stands according to silvicultural and disturbance histories, with dramatic impacts on individual tree growth rates and future wood volume estimates, log and wood product specifications and merchantability.

Plot basal area increment is reported as periodic annual increment, PAI 2007-2013, in Table 3. Overall growth increment of the remaining thinned stand (Regime A) equalled or exceeded that of the unthinned oldgrowth stand (E), even though more than half of the original tree stocking had been removed from Regime A as merchantable thinnings in year 2000 (Table 2).

During the interval 2007-2013, the basal area increment of the regrowth stand (1.39 $m^3ha^{-1}an^{-1}$) reached that of the most poorly performing thinned forest plot (1.30 $m^3ha^{-1}an^{-1}$), but fell appreciably short of the average increments recorded for the thinned and unthinned mature forest stands (2.42 $m^3ha^{-1}an^{-1}$ and 2.15 $m^3ha^{-1}an^{-1}$ respectively, Table 3).

FLORISTIC DIVERSITY

Differences in floristic diversity are presented in Tables 4 and 6. It is no surprise that plant species richness (S) is sensitive to forest management practice and the results reflect the manner in which silvicultural and disturbance histories influence niche opportunities and regeneration success. Maximum density of small trees and of plant species richness in the thinned native forest stand (Regime A) compared to the oldgrowth forest (E) attest to the silvicultural and floristic benefits of heavy thinning disturbance in *E. obliqua* forests, which in part is designed and managed for successful tree regeneration (Tables 2 and 4). In successional terms, early to mid-secondary species such as *E. obliqua* and other fast growing eucalypt species are favoured by such disturbance, especially by opening of the tree canopy and release from competition (Florence 1996). Regeneration of such species is unsuited to dense cover in heavily stocked, undisturbed remnant forest understoreys in the absence of recent fire (Regime E, Table 2).

In 2007, seven years after the thinning operation removed more than two-thirds of the stand basal area (inferred in Table 2), the average number of plant species recorded per small plot in the thinned high forest (22.7$\pm$3.1) significantly exceeded the species richness values recorded for each of the other silvicultural regimes (9.5-14.0). Six years later in 2013, without further disturbance, small gap opportunities for recruitment of pioneer and early secondary species had passed and species richness of the thinned native forest stand (12.7 $\pm$ 1.7) had returned to values similar to both the unthinned oldgrowth forest (12.4) and the then 38 year old regrowth forest (10.4) (Table 6).

Traditional indices of floristic diversity such as Simpson's index (D) and the Shannon-Wiener index (H') represent algebraic combinations of species richness and the evenness of plant species' densities. With minor differences (within one standard error of the means), recorded values of diversity indices D and H' were consistently high for both the thinned and unthinned (oldgrowth) forest stands and slightly less for the regrowth native forest at age 35+ years (Table 4). Diversity values for plantation *E. nitens* at age 15 years were also high for the heavily cut-over ex-bushland sites (Regime C) compared to minimum values recorded for *E. nitens* on ex-pasture sites at age 18 years (Regime B). The difference is attributed to longterm regeneration niche provided by the partial retention of burnt-out windrows following clearfelling of the bushland sites prior to tree establishment. The remnant windrows accounted for the clear majority of plant species which contributed to floristic diversity values in the ex-bushland plantation. In contrast these were not present on the ex-pasture site where the lowest values for both Simpson's Index and Shannon-Wiener Index were recorded.

There is strong support here for the evaluation of forest biodiversity in terms of the dynamics of forest succession, regeneration biology and disturbance ecology of species represented, as opposed to some stereotyped views which commonly and incorrectly attribute maximum floristic and faunal diversity to undisturbed or 'oldgrowth' forest condition. In these results, floristic diversities of native regrowth forest and first rotation ex-bushland plantation are comparably high in both cases in relation to the oldgrowth forest sample (Table 4). Results of individual replicate sample plots also confirm the minor differences which are indicated here for the sample mean values. The analysis also highlights the measurable loss of plant diversity in the ex-pasture plantation sites (Regime B), compared with the ex-bushland sites (C), in keeping with attenuated loss of native flora during the intervening 70-80 years of domestic grazing. The results underline the longer-term importance of the retention of windrows as a means to maintaining residual biodiversity in plantation compartments on ex-bushland sites, within the overall matrix of silvicultural strategies on this forest estate.

[Insert Tables 4, 5 and 6 near here.]

HABITAT CONDITION AND COMPLEXITY

The TasVeg. assessments of 2007 and 2013 and the adapted McElhinny assessment of habitat structural complexity in 2013 each provided the field measurements and obervations for semi-quantitative analysis of forest biodiversity. The respective assessments used different calibrations but were derived from respective observations and measurements of the same plot samples of each forest type and management regime. On each occasion, the surveys were based on the systematic sampling and observation of component structural attributes which, taken together, were used to derive surrogate indices of ecosystem biodiversity.

It is important to note that the total scores for Habitat Condition in 2007 and 2013, (Tables 5 and 6) and the scores for Structural Complexity in 2013 (Table 6) are not measured variables or quantities themselves. They are aggregate rankings of the quality or quantity of a series of observed physical attributes assessed respectively against predefined benchmarks for each of the native forest samples. Although total scores shown here are proportioned within an arbitrary scale of 100 in each case, these are not measured percentages or ratios. The assessments do however provide for the aggregation of pre-defined, semi-quantitative values and attributes relating to habitat structure and condition which together are used as meaningful comparative indices of ecosystem biodiversity. Notwithstanding, there are some limitations eg. in regard to subjective weighting in the TasVeg. analysis, and equal weighting of selected criteria, albeit statistically calibrated, in the McElhinny approach.

There was a closer than expected correlation of the TasVeg. habitat condition index with the results of the floristic analysis described in the previous section (Tables 4-6). Whilst floristic diversity alone is not a complete descriptor of biodiversity in its various forms and dimensions, it is apparent in comparing the two methods of biodiversity assessment that there is a parallel hierarchy of outcomes across the five silvicultural regimes (A-E). This result adds confidence both in the general applicability of the TasVeg. methodology and in the value of the floristic diversity indices themselves as surrogates for a much broader range of ecosystem and habitat attributes which are relevant to the description of biodiversity.

The TasVeg. and McElhinny assessments of native forest diversity showed consistently higher scores for habitat condition and structural complexity in both the unthinned (mature) and thinned *E. obliqua* forests compared to the regrowth forest (Table 6). In 2007, respective values derived for the TasVeg. habitat condition index were 80 for the unthinned (mature) *E obliqua* forest (Regime E), a comparable 81 for the thinned stand (Regime A), and a lesser value of 61 for the 35 year regrowth stand. In 2013, similar (though slightly reduced) values of 77, 75 and 57 were indicated respectively. This pattern is consistent with results derived for floristic diversity in both 2007 and 2013 observations, with the exception of the spike in plant species richness attributed to the thinned high forest samples in 2007 but no longer evident in 2013.

The 2007 and 2013 TasVeg. observations were made by different field crews and the apparent small decline in derived values of the habitat condition index during this period across all three native forest regimes (Table 6) is suggestive of operator differences rather than a short-term loss of habitat structure.

In 2007, the 15 year-old *E. nitens* plantation on windrowed ex-bushland sites (Regime C) showed comparable values to the three native forest regimes (E,A and D) in regard to Species Richness (S), Plant diversity Indices D and H' (Table 4), and several elements of the TasVeg. Score for habitat condition (Table 5). The ecological importance of stored seed and of retaining windrows as a refuge for survival and regeneration of plant species, and for habitat quality generally, is highlighted by comparison with results for the 18 year-old *E. nitens* plantation on the ex-pasture sites (Regime B), which consistently showed significantly reduced values for species richness, plant diversity and habitat condition compared to all other regimes.

Biodiversity studies conducted elsewhere in production native forests report on the poor reliability of using single element biodiversity indicators to distinguish the varying impacts of respective silvicultural regimes (Lindenmayer *et al*., 1999; Oliver *et al*., 2000; Baker, 2006). The comparative results of the two aggregated biodiversity assessment methods applied in this study found a high degree of consistency in estimating the biodiversity value of production forests eg. in differentiating regrowth versus thinned and unthinned *E. obliqua* forest (Table 6). For the 2013 analysis, the adapted McElhinny index of habitat structural complexity also identified the comparably high scores for both thinned and unthinned *E. obliqua* high forest.

Consistent with the TasVeg. analyses of habitat condition in both 2007 and 2013, the McElhinny indices for structural complexity of both the thinned and unthinned *E. obliqua* stands in 2013 exceeded that for the previously cleared regrowth stand, by a wide margin, of similar order to that identified in the TasVeg analyses. Indeed, across the board, the respective scores for species richness, floristic diversity, habitat condition and structural complexity were all much reduced in the regrowth forest compared to the thinned and reserved mature forest sample plots (Table 6). The low biodiversity findings for the young regrowth forests are supported elsewhere by the results of Micheals and McQuillan (1995), Ough and Murphy (1996), Baker *et al*. (2009) and Lefort and Grove (2009) who each found significant decreases in forest biodiversity in response to clearfell silviculture in Tasmanian native forests. However, it is likely that at this farm forestry scale, the magnitude of this difference will decline in future years as the now 35 year old regrowth forest continues to develop a more complex stand structure and diverse internal environment through competition and self-thinning. Hickey (1994) also indicated a decrease in the degree of difference between reserved mature forest and regrowth forest some 20 to 30 years after clearfell harvest in dry sclerophyll forest. Of particular concern in the young regrowth forest and plantations is the absence of large trees with hollows, a feature which can only be created with the development of a mature, spatially complex forest structure over many decades, or by the retention of suitable 'habitat trees' for this purpose.

The occasional hollow stumps and large rotting logs which remain from the clearfell operation of the 1970s provide a partial offset and consequently the presence of coarse woody debris (CWD) contributes significantly to habitat condition and complexity scores for the thinned mature forest (Regime A), the young regrowth forest (Regime D) and the ex-bushland *E. nitens* plantation (Regime C). The amounts of CWD in the thinned forest and regrowth forest surveyed in this study were statistically similar to results for the reserved mature forest, principally due to the waste timber left behind during thinning and clearfelling operations respectively (Smith 2013). However, in the regrowth forest particularly, the absence of large diameter trees and trees with hollows signals an interruption in the availability of important habitat features in consequence of the temporary loss of mature or senescent canopy eucalypts.

CONCLUSION

The floristic and habitat analyses confirm the significant biodiversity contributions made through carefully integrated farm forestry practice, across five different forest management regimes. Indices of floristic diversity were derived in terms of two internationally accepted standards for the estimation of species diversity, each based on a combination of plant species richness and evenness. Forest habitat condition and structural complexity were assessed independently, in relation to specified benchmarks and criteria, based on comprehensively defined habitat features in comparable native forest types.

The case study indicates that at the farm forest scale, an integrated matrix of native forests and plantations can be silviculturally managed for both commercial production and biodiversity protection. Furthermore, with careful planning and skilled forest management, this may be achieved alongside appropriate environmental objectives and a broad basket of social and community benefits.

Analysis indicates that at the farm forest scale, silviculturally managed native *E. obliqua* forests are capable of matching the biodiversity capacity of adjoining oldgrowth forest samples which remain intact. The capacity for biodiversity protection is enhanced further in those regimes which are dependent on a managed degree of forest disturbance, whilst maintaining key elements of forest cover. Opportunities for plant species regeneration and recruitment, and hence the observed diversity of understorey life forms and floristic diversity generally are all maximized in the silviculturally managed high forest compared with neighbouring mature oldgrowth forest on this site.

The results suggest that a dynamic and holistic interpretation of ecosystem biodiversity is required in order to account fully for the observed effects of different forest disturbances, respective management histories and regeneration and production opportunities which are evident at this scale. It is the variety of well-informed forest management strategies and their careful juxtaposition within the one, family-sized landholding, within the one forest landscape and the one integrated forest management framework, which contributes to farm forest productivity and biodiversity protection across this enterprise.

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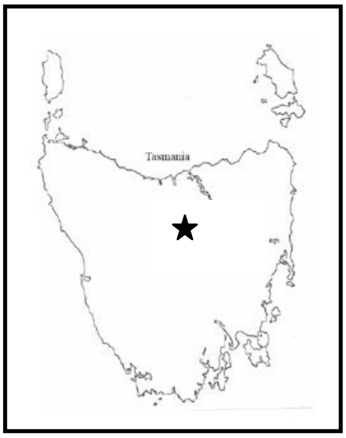
Figure Captions

Fig. 1. *Springmount* and *The Springs*. The 760 ha forested property rises from the Midlands Plain to the foothills of the Western Tiers, in northern Tasmania. Dry regrowth *E. obliqua* forest (then aged 30 yrs) is shown at center left and young *E. nitens* plantations (aged 19 yrs) appear at centre right.

Fig. 2. Location and site plan of the Lord family forests at *Springmount* (lower left) and *The Springs* (upper right) in the Northern Midlands, Tasmania. Patterns show the distribution of native eucalypt forest (striped) and plantations (cross-hachured).



[Inset, upper left corner Fig. 2]

(**Figures 1 and 2 completed and following in separate post)**

Table 1. Component indicators of habitat structural complexity, as applied in the 2013 survey of Dry E. obliqua forest sample plots in September 2013. The method of analysis was adapted from McElhinny *et al.* 2006 and listed benchmarks are those calibrated by Bailey (2012) for application in dry sclerophyll forests elsewhere in the Northern Midlands of Tasmania. Size of sample (quadrats) and number of replicates are listed for each indicator.

Component Indicator	Description and Measurement	Quadrat size (m), number of replicates
Vegetation Cover < 0.5 m	• Estimated cover (%) of vegetation	20 x 20 (3)
Vegetation Cover 0.5 m -6.0 m	• Estimated cover (%) of vegetation	20 x 20 (3)
Perennial species richness	• Count of individual vegetation species	5 x 5 (9)
Life form richness	• Number of vegetation life forms was based on floristic observations, translated to life form and arbitrarily classed as: o Trees (DBHOB $\geq$ 5.0 cm) o Small trees (DBHOB < 5.0 cm, and height > 2 m) o Shrubs and other small woody regeneration (height 0.5-2.0 m) o Low shrubs (<0.5 m height) o Vines o Ferns o Graminoids o Tussock grasses o Non-tussock grasses	5 x 5 (9)
Stand basal area of live trees (m^2 ha^{-1})	• Total basal area of trees (DBHOB $\geq$ 5.0 cm)	20 x 20 (3)

(**Table 1.** continued)

Quadratic mean diameter of live stems (cm)	• Quadratic mean DBHOB (Trees with DBHOB ≥ 5.0 cm)	20 x 20 (3)
Regeneration	• Count of regenerating stems (woody species with DBH < 5.0 cm)	20 x 20 (3)
Hollow bearing trees	• Count of hollow bearing trees	20 x 20 (3)
Dead trees	• Count of dead trees with DBH ≥ 5.0 cm	20 x 20 (3)
Coarse woody debris (CWD)	• Estimated length of all logs with diameter ≥ 10 cm	20 x 20 (3)
Large CWD	• Estimated length of logs with diameter ≥ 30 cm	20 x 20 (3)
Litter dry weight	• Estimated weight of litter (excluding CWD)	5 x 5 (3)

Table 2. Analysis of stand structure in 200m^2 forest sample plots in five forest silvicultural regimes, 2007.
(Values in brackets show Standard Errors for n=3 replicate sample plots.
* Plantation tree density follows 3rd row thinning.)

STAND ANALYSIS in small sample plots (x 3 reps)	Mature Oldgrowth Forest Dry *E. obliqua*	Thinned High Forest Dry *E. obliqua* (2000)	Regrowth Forest Dry *E. obliqua* (mid-70's)	Plantation *E. nitens* ex-bush (1992)	Plantation *E. nitens* ex-pasture (1989)
Silvicultural Regime	E	A	D	C	B
Tree density per ha [+small trees]	425 (35) [300 (70)]	167 (29.0) [350 (150)]	1000 (70) [250 (0.0)]	565* (94)	585* (75)
Tree canopy height (m)	31.8 (0.2)	32.4 (2.3)	22.4 (1.8)	19.9 (1.1)	25.1 (1.7)
No. Tree Species (T)	3.5 (0.7)	2.3 (1.1)	4.0 (0.0)	1.7 (0.6)	1.0 (0.0)
Tree Basal Area (m2 ha-1)	117.7 (34.2)	36.4 (2.9)	48.4 (4.5)	20.0 (1.8)	37.1 (3.9)
% Basal Area (trees $\geq$ 60cm DBH)	76.0 (12.1)	41.7 (1.5)	15.4 (21.7)	0.0	0.0
Foliage Projective Cover (FPC, %)	87.5 (6.5)	44.2 (10.9)	50.7 (8.5)	36.3 (14.2)	60.4 (2.5)

Table 3. Basal Area increment 2007-2013.
Dry *E. obliqua* forest x three silvicultural regimes.

BASAL AREA INCREMENT Summary	Mature Oldgrowth *E. obliqua* forest (6.2007 - 9.2013)	Thinned (2000) *E. obliqua* forest (6.2007 - 9.2013)	Regrowth (1975) *E. obliqua* forest (6.2007 - 9.2013)
Silvicultural Regime	**E**	**A**	**D**
Plot Basal Area 2007 – 2013 (m^2 ha^{-1})	**141.5 – 156.0** **91.7 – 102.9**	**34.2 - 42.3** **26.7 - 50.3** **33.5 - 46.7**	**45.2 - 53.5**
BA increment (PAI, m^2 ha^{-1} an^{-1})	**2.42)** **1.87) 2.15**	**1.30)** **3.81)** **2.14) 2.42**	**1.39**
% BA (Trees ≥ 60cm DBH)	**76.0 - 83.3**	**41.7 - 49.3**	**15.4* - 0.0**
% BA (Trees < 60cm DBH)	**24.0 – 16.7**	**58.3 - 51.7**	**84.6* – 100.0**

Table 4. Floristic analysis of 200m^2 sample plots in five forest silvicultural regimes, 2007.
(Values in brackets show Standard Errors for n=3 replicate sample plots.)

FLORISTIC ANALYSIS in small sample plots (x 3 reps)	Mature Oldgrowth Forest Dry *E. obliqua*	Thinned High Forest Dry *E. obliqua* (2000)	Regrowth Forest Dry *E. obliqua* (mid-70's)	Plantation *E. nitens* ex-bush (1992)	Plantation *E. nitens* ex-pasture (1989)
Silvicultural Regime	E	A	D	C	B
No. Vascular Plants per plot (N)	396 (172)	432 (86)	261 (126)	301 (151)	301 (66)
No. Plant Species per plot (S)	12.5 (0.7)	22.7 (3.1)	9.5 (0.7)	14.0 (3.6)	12.0 (1.0)
Plant Diversity Simpson's Index (D)	0.77 (0.03)	0.74 (0.04)	0.71 (0.01)	0.76 (0.07)	0.61 (0.05)
Shannon-Weiner Index (H')	2.65 (0.36)	2.83 (0.26)	2.28 (0.11)	2.49 (0.50)	2.12 (0.27)

Table 5. Habitat condition analysis in five forest silvicultural regimes, 2007. (TasVeg. Ver.1.0, Michaels 2006)

TASVEG HABITAT SCORE	Mature Oldgrowth Forest Dry *E. obliqua*	Thinned High Forest Dry *E. obliqua* (2000)	Regrowth Forest Dry *E. obliqua* (mid 70's)	Plantation *E. nitens* ex-bush (1992)	Plantation *E. nitens* ex-pasture (1989)
Silvicultural Rergime	**E**	**A**	**D**	**C**	**B**
Large Trees (10)	**10**	**8**	**0**	**0**	**0**
Tree Canopy Cover (5)	**5**	**3**	**5**	**5**	**5**
Lack of Weeds (15)	**15**	**13**	**13**	**13**	**13**
U/storey Life Forms (25)	**15**	**20**	**15**	**15**	**10**
Recruitment (10)	**6**	**10**	**3**	**3**	**3**
Organic Litter (5)	**5**	**5**	**5**	**5**	**4**
Large Logs (5)	**5**	**5**	**5**	**4**	**0**
Patch Size (10)	**10**	**8**	**8**	**8**	**8**
Nearby Native Veg. (10)	**4**	**5**	**3**	**1**	**1**
Connectivity with core (5)	**5**	**4**	**4**	**3**	**3**
TOTAL HABITAT SCORE (100)	**80**	**81**	**61**	**57**	**47**

Table 6. Floristic diversity[1], habitat condition[2] and structural complexity[3] of Dry *E. obliqua* forest in three silvicultural regimes E, A and D respectively, in 2007 and 2013.
(After: 1. Simpson 1949, 2. TasVeg. 2006 and 3. McElhinny *et al.* 2006).

COMPARATIVE BIODIVERSITY INDICATORS	Mature Oldgrowth *E. obliqua* Forest	Thinned (2000) *E. obliqua* Forest	Regrowth (1975) *E. obliqua* Forest
Silvicultural Regime	E	A	D
No. Plant Species (S) 2007 2013	12.5 (0.7) 12.4 (3.2)	22.7 (3.1) 12.7 (1.7)	9.5 (0.7) 10.4 (1.7)*
Simpson's Index (D) 2007	0.77 (0.03)	0.74 (0.04)	0.71 (0.01)
TasVeg. HABITAT CONDITION 2007 (100)	80	81	61
TasVeg. HABITAT CONDITION 2013 (100)	77	75	57
STRUCTURAL COMPLEXITY 2013 (after McElhinny *et al.* 2005)	71	76	55